(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 February 2002 (28.02.2002)

PCT

(10) International Publication Number
WO 02/17534 A1

(51) International Patent Classification[7]: H04J 14/02

(21) International Application Number: PCT/US01/26587

(22) International Filing Date: 23 August 2001 (23.08.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/648,714 25 August 2000 (25.08.2000) US

(71) Applicant: **CENTERPOINT BROADBAND TECHNOLOGIES, INC.** [US/US]; 1741 Technology Drive, Suite 400, San Jose, CA 95110 (US).

(72) Inventors: **WOLCOTT, Theodore, John**; 505 Cypress Point Drive, Unit 196, Mountain View, CA 94043 (US). **STILES, William, Herschel**; 5936 Killarney Circle, San Jose, CA 95138 (US). **VALDEZ, Abelino, C.**; 1691 Ash Tree Way, Tracy, CA 95376 (US). **VAN FLETEREN, Stephan, Rene**; 453F Cork Harbour Circle, Redwood City, CA 94065 (US). **LE, Chu, Duc**; 1021 Basilwood Drive, Coppell, TX 75019 (US).

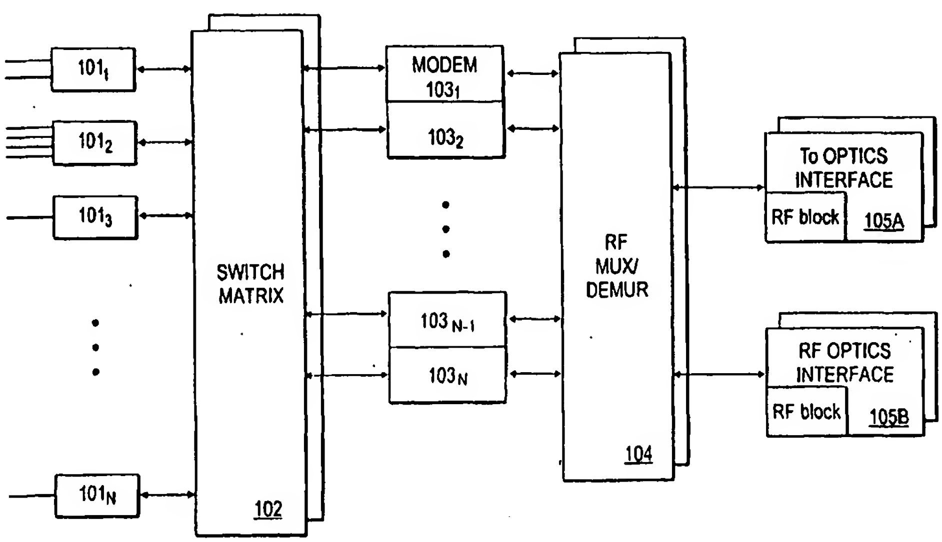
(74) Agents: **MALLIE, Michael, J.** et al.; Blakely, Sokoloff, Taylor & Zafman LLP 12400 Wilshire Boulevard, 7th Floor, Los Angeles, CA 90025 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: A FIBER OPTIC TERMINAL SYSTEM EMPLOYING SUBCARRIER MULTIPLEXING FOR HIGH CAPACITY OPTICAL DATA TRANSPORT



(57) Abstract: A system and method employing subcarrier multiplexing is described. In one embodiment, the system comprises tributary interfaces (101), modems (103), frequency converters, a radio frequency (RF) multiplexer (104), and an optical transmitter (105A). The tributary interfaces (101) accept input data channels. The modems (103), which are coupled to the tributary interfaces (101), modulate the input data channels onto an intermediate frequency (IF) carrier. The frequency converters, which are coupled to the modems (103), translate the input IF channels to RF frequencies. The RF multiplexer (104), which is coupled to the frequency converters, combines RF channels. The optical transmitter (105A) is coupled to the RF multiplexer (104) and modulates the combined RF channels onto an optical carrier and then transmit the signal into a fiber.

WO 02/17534 A1

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A FIBER OPTIC TERMINAL SYSTEM EMPLOYING SUBCARRIER MULTIPLEXING FOR HIGH CAPACITY OPTICAL DATA TRANSPORT

FIELD OF THE INVENTION

The present invention relates to the field of subcarrier multiplexing; more particularly, the present invention relates to an architecture for performing subcarrier multiplexing and a method for doing the same.

BACKGROUND OF THE INVENTION

Traditional systems rely on Synchronous Optical NETworks (SONET) standards to time division multiplex multiple channels into a single high rate data stream. Today's SONET systems are limited to rates of approximately 10 Gbps. Future SONET systems will operate at 40 Gbps.

Traditional SONET systems require all data channels to operate at precise, fixed data rates, based on a common reference clock. The SONET standard and SONET networks were designed and are optimum for voice traffic and are poor for data channels which typically do not operate at SONET standard rates. As the ratio of data traffic to voice traffic increases, SONET networks become increasingly inefficient and require additional equipment to convert the non-SONET data channels to SONET standard channels. Also, since all of the tributaries are multiplexed into a single high rate channel, the digital circuitry must operate fast enough to support the aggregate data rate, up to 10 Gbps for SONET OC-192 systems. Such digital circuitry is very expensive due to the high clock rate. The cost will increase dramatically for 40 Gbps SONET.

Furthermore, SONET systems operate with on/off keyed modulation. Such modulation is one of the most bandwidth inefficient modulation schemes. As such, SONET systems make poor use of the available bandwidth.

Moreover, SONET systems do not scale. That is, a 10 Gbps SONET system must operate at 10 Gbps. If the tributaries do not combine to fill the entire 10 Gbps, dummy bits are added in the unused channels such that the total

rate is 10 Gbps. Thus, the entire cost of a 10 Gbps system must be incurred, even if only 5 Gbps capacity is required.

New systems employ Dense Wavelength Division Multiplexing (DWDM) to increase the capacity of a single fiber by transmitting multiple SONET signals on different wavelength optical carriers.

Use of DWDM mutiplies the capacity of a single fiber, but requires multiple expensive lasers (one for each optical carrier). Even with DWDM, each carrier is limited to 10 Gbps today. With 100 GHz channel spacing, the bandwidth efficiency is still on the order of 0.1 bits/second/Hertz. This can be increased to 0.2 bps/Hz with channel spacing of 50 GHz, which is still poor. 40 GHz SONET systems will not operate with 50 GHz spacing since such a system requires 80 GHz of specturm. Therefore, with 50 GHz channel spacing, DWDM systems transporting SONET format channels on each wavelength can transmit a maximum of 10 Gbps.

SUMMARY OF THE INVENTION

A system and method employing subcarrier multiplexing is described. In one embodiment, the system comprises tributary interfaces, modems, frequency converters, a radio frequency (RF) multiplexer, and an optical transmitter. The tributary interfaces to accept input data channels. The modems, which are coupled to the tributary interfaces, modulate the input data channels onto an intermediate frequency (IF) carrier. The frequency converters, which are coupled to the modems, translate the input IF channels to RF frequencies. The RF multiplexer, which is coupled to the frequency converters, combines RF channels. The optical transmitter is coupled to the RF multiplexer and modulates the combined RF channels onto an optical carrier and then transmit the signal into a fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood more fully from the detailed description given below and from the accompanying drawings of various

embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1 is a block diagram of one embodiment of an architecture of the system.

Figure 2 illustrates an exemplary frequency plan.

Figure 3 is a block diagram of one embodiment of a portion of the architecture of the system responsible for generating the waveform of Figure 2.

Figure 4 illustrates an alternative embodiment of a dual modem card with an upconverter plugged in to support both modems.

Figure 5 illustrates a more detailed view of one embodiment of an RF mux/demux and modem coupling.

Figure 6 illustrates one embodiment of a portion of the architecture in which modem boards are stacked together with multiplexers laying across the modem boards in an orthogonal position.

Figure 7 is a block diagram of one embodiment of a modem.

Figure 8 illustrates an exemplary data flow.

Figure 9 is a block diagram of one embodiment of an optical transmitter.

Figure 10 is a block diagram of one embodiment of an optical receiver.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

A system and method employing subcarrier multiplexing is described. In the following description, numerous details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

Some portions of the detailed descriptions that follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer

system memories or registers or other such information storage, transmission or display devices.

The present invention also relates to apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may comprise a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions, and each coupled to a computer system bus.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes read only memory ("ROM"); random access memory ("RAM"); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.); etc.

Overview

A Fiber Optic Terminal System (FOTS) is described below. In one embodiment, the FOTS system may be used for metropolitan, regional, and long

haul transport. The transport may comprise voice, data and/or video. The FOTS system uses subcarrier multiplexing (SCM) by which multiple independent channels (e.g., data, voice, video, etc.) can be carried on a single optical carrier. The FOTS communication system modulates the aggregate of the modulated RF carriers onto an optical carrier before transmitting the channels together through a fiber optic cable.

The FOTS employs SCM to transport multiple voice or data channels form one location to another, over many kilometers of standard single mode fiber optic cable, non-zero dispersion shifted single-mode fiber optic cable, large effective area fiber (LEAF), and others. In one embodiment, the FOTS transmits up to 32 SCM channels, each operating at a rate up to 622 Mbps (1Mbps = $1X10^6$ bits per second), using a single optical carrier. In another embodiment, the FOTS transmits up to 32 SCM channels at up to 622 Mbps each, or up to 8 SCM channels at up to 2.5 Gbps each, or a combination of channels at 622 Mbps and 2.5 Gbps each — four channels at 622 Mbps each can be substituted for any one of the eight channels at 2.5 Gbps each.

In one embodiment, the FOTS is a bi-directional system, made up of a transmit and receive section. By placing a single FOTS at each end of a fiber optic link (two fiber optic cables, or a single fiber optic cable if two wavelengths are employed) (fiber and optical amplifiers, DWDM equipment, all optical switched, etc...), bi-directional communication at an aggregate rate up to 40 Gbps (20 Gbps in each direction) is possible. The FOTS may also be used in conjunction with, optical amplifiers, DWDM equipment, optical switches, etc.

In one embodiment, the FOTS employs time division multiplexing (TDM) techniques to combine multiple lower rate channels into a single channel at a rate up to 622 Mbps (current implementation) or 2.5 Gbps (future implementation), which is then transmitted over on of the SCM channels. By doing so, the FOTS can accept many input channels at rates at or below 622 Mbps (current implementation) or 2.5 Gbps (future implementation), limited to a total transmission capacity of no more than 20 Gbps. At the far end of the fiber

channel, the FOTS demultiplexes the channels appropriately to re-create the individual channels multiplexed by the FOTS prior to transmission.

In one embodiment, the FOTS can accept input channels at rates greater that 622 Mbps by demultiplexing (in time) the high rate channels into multiple channels at rates at or below 622 Mbps prior to transmission. The FOTS receiver then multiplexes these channels into a single high rate channel, regenerating the input channel. Channels at rates below 622 Mbps can be multiplexed into single channels at rates equal to or less than 622 Mbps.

In one embodiment, each of 32 modems can operate at either 622 Mbps or 1.0 Gbps. So, the capacity can go as high as 32 Gbps. Currently, the system is designed to carry Gigabit Ethernet on 1 or 2 subcarriers.

The SCM system described herein employs modulation techniques which make much better use of the available bandwidth. In one embodiment, the SCM transports up to 20 Gbps on a single wavelength. Furthermore, the SCM system does not require a relationship between the rates of the tributary channels. Therefore, each channel can be at a different rate and is capable of transporting data channels in their native format (and rate) without conversion to the SONET standard rates and format. Since each subcarrier operates independently, there is no need to transport data on unused channels. Equipment associated with unused channels is not needed and can be eliminated from the system. Thus, the size and cost of the system can be scaled as needs increase.

Since the multiplexing of the subcarriers is performed in the analog RF domain, the circuitry associated with each subcarrier channel need only operate fast enough to support transmission of that particular channel. Therefore, the fastest digital circuitry must only operate fast enough to transmit the fastest tributary channel, much slower than the aggregate data rate. Since the circuitry operates at much lower clock rates, compared to SONET systems, it is much less expensive.

The optical signal created by the FOTS described herein is compatible with DWDM technology with special considerations. Thus, multiple LENS FOTS signals can be conveyed on a single optical fiber by transmitting each

FOTS signal on a different DWDM compatible wavelength. Likewise, FOTS signals can be combined with other optical transmission system signals, such as traditional Synchronous Optical Network (SONET) signals, provided all signals are DWDM compatible.

The Architecture

The architecture of the system comprises multiple subsystems. These subsystems include tributary interfaces (e.g., cards), modems, frequency converters, a RF multiplexer & demultiplexer, and an optical transceiver and receiver.

The tributary interfaces accept the input data channels for transmission by the FOTS and format the output data channels after reception by the FOTS. The modems modulate the input data channels onto an intermediate frequency (IF) carrier for transmission by the FOTS and demodulate the output data channels from an intermediate frequency (IF) carrier after reception by the FOTS. The frequency converters translate the input IF channels to the proper RF frequencies for transmission by the FOTS and translate the output RF channels to the proper IF frequency after reception by the FOTS. The RF multiplexer & demultiplexer combines input RF channels for transmission by the FOTS and separates the combined output RF channels after reception by the FOTS, respectively, while the optical transmitter & receiver modulate the combined RF channels onto the optical carrier and then transmit the signal onto the fiber and receive the optical signal and recover the combined output RF channels, respectively.

Any number of frequency conversions may be used to get to and from the desired frequency. Alternatively, the modems could modulate directly to the desired frequency and demodulate from that frequency, thereby eliminating the need for frequency converters.

It should be noted that although subsystems or other system elements are described herein with both transmission and reception capabilities, in some embodiments, such subsystems and system elements may only perform functions associated with transmission or reception.

Figure 1 illustrates one embodiment of an architecture for a fiber optic terminal system employing subcarrier multiplexing for high capacity optical data transport. Referring to Figure 1, the architecture comprises a series of tributary interfaces 101_1-101_N, a switch matrix 102, modems 103_1-103_N, radio frequency (RF) multliplexer (mux)/demultiplexer (demux) 104, and transmit (Tx) optics interface 105A and receive (Rx) optics interface 105B. Each of these subsystems may be implemented on one or more cards, or they may be combined on one or more cards. In one embodiment, switch matrix 102, modem cards 103, RF mux/demux 104 and optics interfaces (e.g., cards) 105A-B have redundant counterparts in order to handle subsystem and/or component failure.

During transmission, tributary interfaces 101_1-101_N accept input data and supply the input data to switch matrix 102. In one embodiment, each of tributary interfaces 101_1-101_N includes an optical transceiver that performs an optical to electrical conversion and processing to accommodate the channel type the interface is designed to receive, such as, for example, OC-3, OC-12, OC-48, a 625 Mbps signal, etc.

In one embodiment, each of tributary interfaces 101_1-101_N comprises a card that receives two OC-12 data streams, a card that receives four OC-3 data streams, a card that receives one OC-48 data stream, or a card that receives on OC-192 data stream. In any case, the tributary interface converts the data streams to a common output type. In one embodiment, tributary cards 101_1-101_N convert input data to an OC-12 rate for output. For example, in the case of a tributary card accepting four OC-3 streams, the tributary card multiplexes the signals up to an OC-12 rate using standard multiplexing schemes. In the case of a tributary card that accepts a single OC-48 stream, the tributary card splits the input stream into four OC-12 streams using standard demultiplexing schemes. An OC-192 stream is split into 16 OC-12 streams.

Other tributary interfaces may interface Gigabit Ethernet or Fibre Channel to the system. A Gigabit Ethernet card can split the 1.25 Gbps Gig E data stream (which includes 8b10b encoding for error protection) into 2 625

Mbps streams. Or, the 8b10b coding may be removed and the 1 Gbps signal is applied directly to a modem.

During reception, tributary cards 101_1-101_N format the data channels for output to the correct type (e.g., OC-3, OC-48, etc.).

During transmission, switch matrix 102 receives the data streams of the same type (e.g., OC-12) from tributary interfaces 101_1-101_N and transfers them to modems 103_1-103_N.

In one embodiment, the switch matrix is provisioned for connectivity between tributaries — one or more tributaries are connected to one or more modem cards. In this case, those connections are held until the switch matrix is re-provisioned. The full 622 mbps stream is switched.

In one embodiment, the OC-12 bit streams are broken down into their constituent STS-1 channels (an OC-3 is made up of 3 STS-1 channels; an OC-12 is made up of 12 STS-1 channels; etc...). The individual STS-1 channels are routed to one or more output ports such that each modem receives a newly constructed OC-12 rate bit stream.

In one embodiment, header information may be used to route individual packets, carried in the OC-12 bit stream.

During reception, switch matrix 102 transfers signals from modems 103_1-103_N to tributary interfaces 101_1-101_N.

During transmission, modems 103_1-103_N modulate the input data channels received from switch matrix 102 onto an intermediate frequency (IF) carrier, while during reception, modems 103_1-103_N demodulate output data channels from an IF frequency carrier. In an alternative embodiment, no intermediate frequency is used.

Frequency converters (not shown) are coupled to modems 103_1-103_N and translate the IF signals output by modems 103_1-103_N to generate a set of RF channels each at a different RF frequency during transmission. In one embodiment, the set of RF frequencies are those that are proper for transmission by the FOTS and will be described in later detail below.

In one embodiment, the channels are from 2-16GHz and can be divided into two parts. Essentially two signals are in the upper band with sub-bands within each band. One of the upper bands is processed to create a lower band. This lower band is combined with the unchanged upper band to create the single set of channels running form 2-16 GHz.

During reception, the frequency converters translate the output RF channels to an IF frequency.

RF mux/demux 104 performs combines input RF channels. In one embodiment, RF mux 104 generates band A and band B and sends them to optics interface 105A for transmission. RF demux 104 separates combined output RF channels during reception.

Optics interface 105A modulates the combined RF channels onto an optical carrier and then transmits the signal onto an optical fiber. In one embodiment, multiple such signals, each at a different wavelength and generated by a similar architecture, are combined using an optical combiner and then applied to the optical fiber for transmission.

Optics interface 105B receives an optical signal and recovers combined RF channels. Receipt of the optical signal may comprise filtering an optical signal to receive only a signal wavelength (from a optical signal having many wavelengths previously combined). In one embodiment, each of optics interfaces 105A-B includes an RF block to facilitate the interface with RF mux/demux 104. The RF block performs a frequency conversion of a lower band of channels to/from an upper band of channels and recombines and/or splits the two bands. This is described in more detail below.

In one embodiment, optical amplifiers and/or dispersion compensation modules (e.g., fiber, gratings, etc.) between the fiber optic cable and the optical transmitter and/or optical receiver may be added.

<u>An Exemplary Frequency Plan</u>

Figure 2 illustrates an exemplary frequency plan for 32 subcarriers. Referring to Figure 2, subcarriers 1-16 (low band spectrum) are separated

slightly more in frequency from subcarriers 17-32 (high band spectrum) in order to efficiently up convert (and flip) the lower subcarriers (1-16) to the higher frequencies (17-32) without requiring tight filtering techniques. By up converting the lower frequencies to the higher frequencies, the number of frequency converters is reduced, bandwidth is now a signal octave, 8-16 GHz, bandwidth, and the RF component sizes are reduced.

Figure 2 also shows one embodiment of the IF channel. The IF frequency is the frequency the modems and the frequency converters use to pass subcarriers between each other. The modems take the subcarriers at the IF frequency from the frequency converters and down-converts the spectrum to baseband for processing by the modem's analog-to-digital (A/D) converters and modem ASICs. In the reverse direction, after processing by the modem ASICs and the digital-to-analog (D/A) converters, the baseband signal is up-converted to IF for the transmission to the frequency converters.

Referring again to Figure 2, the local oscillator positioning of the frequency converters is shown. These local oscillators, in conjunction with the mixers, are used to move subcarriers between IF and the high-band subcarrier slots. In one embodiment, their positioning is such that they fall between OC-12 subcarriers to reduce, and potentially minimize, direct interference. Note that the local oscillator spectrum is not typically transmitted across the fiber.

From the perspective of the waveform, in one embodiment, is a gap to facilitate the folding. That is, everything is being done in the high frequency side (e.g. 9.8-15.8GHz) and then half of the waveform is being folded down. The gap is wide enough so that the folding can occur and the waveform can be filtered without a lot of very expensive filters. The other benefit of the gap is that in order to evolve from OC-12 to OC-48 the channels are spaced in the waveform so that form may be removed and the OC-48 channel will fit.

The waveform of Figure 2 is developed using frequency division multiplexing via RF mux/demux 104.

Figure 3 is a block diagram of a portion of one embodiment of the architecture with a more detailed view of the RF mux/demux and upconverters.

Referring to Figure 3, modem $301_1 - 301_N$ provide inputs to upconverters 302_1-302_N. The inputs of upconverters 302_1-302_N are coupled to receive data from modems 301_1-301_N. The outputs of upconverters 302_1-302_N are coupled to inputs of multiplexer (mux) 303. The output of mux 303 is coupled to power combiner 304. The output of power combiner 304 is coupled to optical transmitter 305.

A duplicated portion of the circuitry is also included in Figure 3. Modems $311_1 - 311_N$ provide inputs to upconverters 312_1-311_N. That is, the inputs of upconverters 312_1-311_N are coupled to receive data from modems 311_1-311_N. The outputs of upconverters 312_1-312_N are coupled to inputs of multiplexer (mux) 313. The output of mux 313 is coupled to an input of downconverter 320. The output of down converter 320 is coupled to the input of power combiner 304.

In one embodiment, modems $301_1 - 301_N$ and $311_1 - 311_N$ are implemented on cards, with each card having two modems. Each modem card accepts two serial digital data streams from its corresponding switch matrix card (of switch matrix 103). The modems modulate the signals and forward them to the upconverters.

In one embodiment, as shown in Figure 2, the waveform ranges from 2 and 18 GHz, while the output of individual ones of modems 301_1-301_N is 1.8 GHz. In one embodiment, the outputs of modems 301_1-301_N and 311_1-311_N are combined into a waveform having a range from 2 to 18 GHz by taking the 1.8 GHz signals from the modems and inputting them to upconverters 302_1-302_N and 311_1-311_N. Each of the upconverters outputs one of these channels. For example, upconverter 302_N upconverts the 1.8 GHz to 9.8 GHz. Each subsequent upconverter generates a channel spaced 400 megahertz (MHz) from the previous one. Therefore, the next channel would be 10.2 GHz; the last is 15.8 GHz. Similarly the outputs of upconverters 312_1-312_N output a spectrum for 9.8-15.8 GHz.

Mux 303 and 313 receives outputs from upconverters 302 and 312, repeatedly, and combine the output to a single output.

Downconverter 320 downconverts the output of mux 313 from a spectrum ranging from 9.8-15.8 GHz to one ranging from 1.8-8.8 GHz.

The output of downconverter 320 and mux 303 are summed together by power combiner 304 to produce a waveform from 1.8-15.8 GHz. The output power combiner 304 is coupled to the input of optical transmitter 305, which generates an optical signal representing the 32 channel waveform, and this is the waveform that is put on the fiber. This waveform may be coupled to one or more optical transmitters, creating multiple optical signals at one or more optical carrier wavelengths.

One advantage of the approach described above is that 32 different upconverters do not have to be built. Because the downconversion occurs after the spectrum is created, only 16 upconverters are needed and duplicated.

In one embodiment, an upconverter module is shared by one dual modem card. In such a case, only 16 different upconverter modules are needed, with two upconverters to accommodate the two modems. Figure 4 is a block diagram illustrating a single upconverter being shared by one dual modem card. This also allows the modems to be unassigned a specific frequency until the upconverter is attached (e.g., plugged in) to brand the output of the modems to specific channels at specific frequencies.

Note that the description above of Figure 3 is discussed in terms of transmission; however, the operation of each of the components is reciprocal and performs the opposite function when processing simply in the reverse direction. For example, power combiner 304 operates as a power splitter. Downconverter 320 operates as an upconverter, while upconverters 302_1-302_N and 312_1-312_N operate as downconverters.

Figure 5 is a block diagram of an alternative view one embodiment of the mux and signal processing from or to the modem. The frequency convertors have not been shown to avoid obscuring the present invention. Referring to Figure 5, modems 501_1-501_N are coupled to send signals to and receive signals from a pair of muxes 502 and 503. Mux 502 combines signals received from modems 501_1-501_N and sends the aggregate signal to an optical transmitter (e.g.,

board), while receive mux 503 receives a signal from the optical receiver (e.g., board) and sends signals to each of modems 501_1-501_N. In one embodiment, N is 16.

In one embodiment, each mux 502 or 503 includes band pass filters to filter the signals to prevent channel interferance. There is also a summing network in transmit mux 503 that receives the outputs of each of the band pass filters and sums them together at a summing point before forwarding the combined signal to the optical transmitter. In the reverse direction, the receive mux includes a signal divider to divide the signal received from the optical receiver and forwards the resulting signals to modems 501_1-501_N.

In one embodiment, modems 501_1-501_N comprise boards that are stacked together and muxes 502 and 503 lay across the modem boards in an orthogonal position, such as shown in Figure 6.

Figure 7 is a block diagram of one embodiment of a modem. Referring to Figure 7, modem 700 comprises modulation ASIC 701B, digital-to-analog (D/A) converter 702, intermediate frying (IF) modulator 703, demodulator ASIC 704, A/D converter 705, IF demodulator 706, clock recovery logic 707, a carrier recovery block 708, and control/status bus 710.

Modulator ASIC 701 accepts digital data to be transmitted. In one embodiment, the inputs to modulator 701 comprise eight bits of data and a clock-in signal. In response to these inputs, modulator ASIC 701 creates two eight bit words and a clock. The clock signal generated by ASIC 701 is different from the clock-in signal.

Modulator ASIC 701 also performs various DSP tasks such as scrambling, Reed-Solomon forward error correction (FEC) encoding, interleaving, trellis coded modulation encoding, and some miscellaneous functions (e.g., scrambling, interleaving, etc.). Modulator ASIC 701 generates a digital representation of the signal to be transmitted. The outputs of modulator ASIC 701 are coupled to inputs of D/A converter 702, which converts the digital transmission signals to analog base band transmission signals. In one

embodiment, a dual D/A converter is used to take 2 digital inputs and creates 2 analog outputs.

The outputs of the D/A converter 702 coupled to inputs of IF modulator 703. IF modulator 703 takes the analog base band signal and modulates it (16 QAM) signal onto an IF carrier. In one embodiment, the IF modulator also includes linearizer functionality. In one embodiment, the output of the IF modulator 703 is a 1.8 GHz IF transmission signal.

In the reverse direction, the demodulation blocks perform the opposite functions as the modulation blocks do. That is, IF demodulator 706 receives a 1.8 GHz analog signal and performs equalization and demodulation to create a base band IQ signal. The outputs of IF demodulator 706 are coupled to inputs of A/D converter 705, which converts the analog base band signals to a digital signal. In one embodiment, A/D converter 705 generates two eight bit outputs and a clock signal. The outputs of A/D converter 705 are coupled to inputs to the demodulation ASIC 704 which performs equalization, trellis coded modulation decoding, deinterleaving, Reed-Solomon FEC decoding and descrambling. The outputs include an eight bit data and a clock out signal.

The clock recovery block 707 and carrier recovery block 708 perform clock and carrier recovery, respectively, in a manner well known in the art. A control and status bus 710 controls the operations of the various blocks.

An Exemplary Optical Transmitter

Figure 9 is a block diagram of one embodiment of an optical transmitter. Referring to Figure 9, the RF signal at the output of RF block 901 is amplified by a variable gain amplifier 902, which is coupled to an external optical modulator 903 (e.g., a Mach Zehnder, or linearized Mach Zehnder, interferometer, etc.). A laser 904 is coupled to external modulator 903, which modulates the optical carrier created by laser 904 according to the RF signal. An optical coupler 905, coupled to the output port of external modulator 903, extracts a small portion of the modulated optical signal. This signal is coupled to a photo detector 906. The electrical port of photo detector 906 is coupled to a control circuit 907, which

controls the wavelength and power of laser 904 as well as the bias level of external modulator 903. The primary port of optical coupler 905 is coupled to a fiber optic cable.

An Exemplary Optical Receiver

Figure 10 is a block diagram of an optical receiver. Referring to Figure 10, a fiber optic cable is coupled to a photo detector 1001 (i.e., photo diode, avalanche photo diode, etc.). Photo detector 1001 is coupled to a low noise amplifier (LNA) 1002 which boosts the power level of the received signal. LNA 1002 is coupled to receive RF block 1003.

In one embodiment, the optical transmitter and transmit RF block are on one card and the optical receiver and receive RF block are on another. In an alternative embodiment, the optical transmitter, the transmit RF block, the optical receiver, and the receive RF block are on a single card together.

Exemplary Data Flow

Figure 8 illustrates data flow between tributary interfaces (e.g., cards), switch matrices, and the modems. In one embodiment, the data being input or output to the tributary cards is OC-3 data, OC-12 data, or OC-48 data. In one embodiment, all the data from the input to the tributary cards is converted into OC-12 data and sent through to the modems via the switch matrix.

Referring to Figure 8, tributary cards 901_1-901_N are coupled to switch matrices 902_1 and 902_2. Multiple modems, groups A and B, are coupled to switch matrices 902_1 and 902_2. In one embodiment, 16 banks of modems are coupled to switch matrix 902_1 and 16 banks of modems are coupled to switch matrix 902_2.

It should be noted that all the connections are bi-directional between the components. The tributary cards receive signals from both switch matrices, determine which one is of better signal quality, and output that signal to the customer. Similarly, the tributary cards send signals to both switch matrices, which are forwarded to the modems. Thus, this configuration shows a complete redundant path between the optics board and the tributary cards.

Each bank of modems includes 2 modems, 1 for each channel. In the A group of modems, there is one modem for each subcarrier. Similarly, in the B group of modems, there is a modem for each subcarrier that matches the subcarrier of one of the cards in group A. Switch matrix 902_2 and the B group of modems provide a redundant path for channels. In other words, if such redundancy was not required in the system, this path would not be necessary.

In an alternative embodiment, tributary cards are also made to be redundant. In such a case, the two identical tracking streams are sent to the customer, and the customer can actually select the better of the two, particularly if one of the tributary cards has failed.

Referring back the Figure 8, tributary card 701_1 comprises an example of an OC-12 card that receives OC-12 data, splits it, sending a copy to switch matrices A and switch matrices B. Similarly, signals from switch matrices A and switch matrices B are sent to a mux in tributary card 701_1 which selects the better of the two signals for output back to the customer. A second input and output port has not been shown to avoid obscuring the present invention.

Tributary card 701_2 comprises an OC-3 card which has four inputs and four outputs, numbered 1, 2, 3, and 4. The OC-3 data is muxed using mux 920 to combine the four OC-3 streams into OC-12 data that is output to both switch matrix A and switch matrix B. Such muxing is well known in the art. In the reverse direction, a mux 930 receives a signal from each of switch matrices A and B. The output of mux 930 is selected based on the signal quality and the selected signal is sent to a demux 940 which performs a demultiplexing function to generate four OC-3 signals from an OC-12 signal.

One embodiment of an OC-48 tributary card includes a demultiplexor that receives an OC-48 stream and splits it into four OC-12 streams. The four OC-12 streams are then output to each of the switch matrices. Similarly, the signals received from switch matrices A and B are received by a pair of muxes which select signals based on the quality. Those signals are then output from a mux to the output port of the TIU. An example of the OC-48 tributary card is described in copending application serial no. __, entitled "Identical Frame/Data

Reconstruction of High Rate Optical Signals Using Parallel Transmission", filed ____________, and assigned to the corporate assignee of the present invention.

Whereas many alterations and modifications of the present invention will no doubt become apparent to a person of ordinary skill in the art after having read the foregoing description, it is to be understood that any particular embodiment shown and described by way of illustration is in no way intended to be considered limiting. Therefore, references to details of various embodiments are not intended to limit the scope of the claims which in themselves recite only those features regarded as essential to the invention.

Thus, a communication system has been described.

CLAIMS

We claim:

1. A system comprising:

a plurality of tributary interfaces to accept input data channels;

a plurality of modems coupled to the plurality of tributary interfaces to modulate the input data channels onto an intermediate frequency (IF) carrier;

a plurality of frequency converters coupled to the plurality of modems to translate the input IF channels to RF frequencies;

a radio frequency (RF) multiplexer coupled to the plurality of frequency converters to combine RF channels; and

an optical transmitter coupled to the RF multiplexer to modulate the combined RF channels onto an optical carrier and then transmit the signal into a fiber.

2. The system defined in Claim 1 further comprising a switch matrix coupling the plurality of tributary interfaces to the plurality of modems.

3. The system defined in Claim 1 wherein the frequency converters comprise a plurality of upconverters.

4. The system defined in Claim 3 wherein at least a portion of the plurality of upconverters comprise a dual upconverter for a dual modem card.

5. The system defined in Claim 1 wherein the plurality of modems perform the function of the plurality of frequency converters by modulating signals directly to the RF frequencies.

6. The system defined in Claim 1 wherein the frequency converter comprises:

a first plurality of upconverters coupled to different modems of a first group of modems in the plurality of modems to convert signals from the first group of modems to different frequencies to create a first group of signals;

a first summer coupled to receive the first group of signal from the first plurality of upconverters to create a first band;

a second plurality of upconverters coupled to different modems of a second group of modems in the plurality of modems to convert signals from the second group of modems to different frequencies to create a second group of signals;

a second summer coupled to receive the second group of signal from the second plurality of upconverters to create a second band;

a converter coupled to the second summer to convert the second band into a third band having a spectrum different than the first band;

a third summer coupled to receive outputs of the first summer and the converter to sum the first band and the third band together to create a waveform.

7. The system defined in Claim 6 wherein the converter comprises a down converter.

8. The system defined in Claim 6 wherein the power combiner comprises a diplexer.

9. The system defined in Claim 6 wherein the first and second summers comprise multiplexers.

10. The system defined in Claim 6 wherein the first and second groups of upconverters convert signals from modems of the plurality of modems into signals having a 0.4 GHz spacing.

11. The system defined in Claim 6 wherein the first and second bands are from approximately 9.8 GHz to 15.8 GHz.

12. The system defined in Claim 6 wherein the third band is from approximately 1.8 GHz to 8.8 GHz.

13. The system defined in Claim 1 wherein the plurality of tributary interfaces comprise one or more from the group of OC-3, OC-12, OC-48 TIU, Fibre Channel, and Gigabit Ethernet cards.

14. The system defined in Claim 1 wherein the plurality of tributary interfaces comprise tributary cards.

15. A system comprising:

an optical receiver to receive optical signals and recover combined output RF channels therefrom;

a radio frequency (RF) demultiplexer coupled to the optical receiver to separate the combined output RF channels into separate RF channels;

a plurality of frequency converters coupled to the RF demultiplexer to translate the output RF channels to an IF frequency;

a plurality of modems coupled to plurality of frequency converters to translate the output RF channels to the proper IF frequency; and

a plurality of tributary interfaces coupled to the plurality of modems to format output data channels during reception.

16. A system comprising:

a plurality of tributary interfaces to accept input data channels during transmission and formats output data channels during reception during reception;

a plurality of modems coupled to the plurality of tributary interfaces to modulate the input data channels onto an intermediate frequency (IF) carrier

during transmission and to translate the output RF channels to the proper IF frequency during reception;

a plurality of frequency converters coupled to the plurality of modems to translate the input IF channels to RF frequencies during transmission and to translate the output RF channels to an IF frequency during reception;

a radio frequency (RF) multiplexer and demultiplexer to combine RF channels during transmission and to separate the combined output RF channels during reception; and

an optical transmitter and receiver to modulate the combined RF channels onto an optical carrier and then transmit the signal into a fiber and to receive optical signals and recover combined output RF channels therefrom.

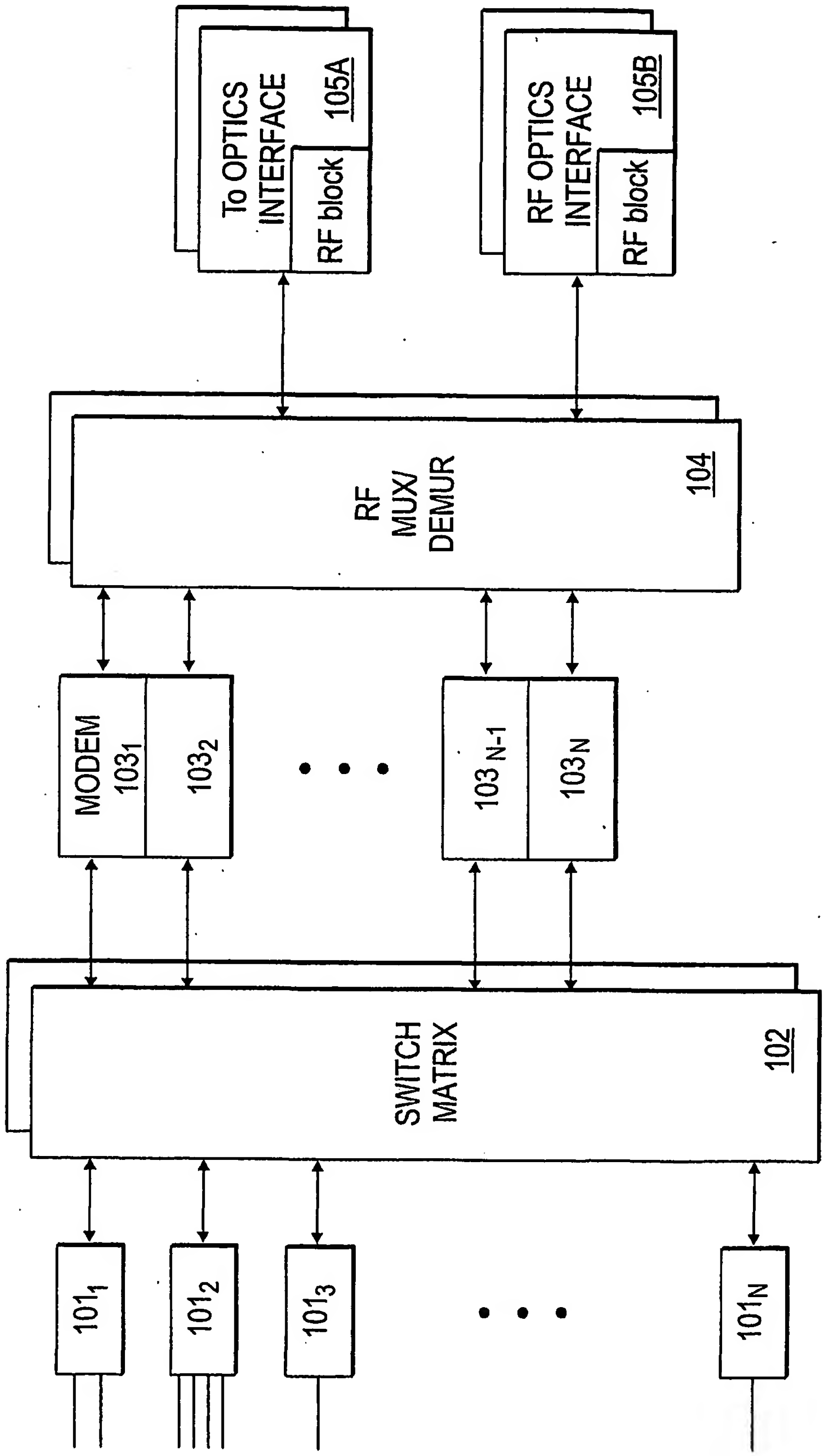

To OPTICS
INTERFACE
105A
RF block
RF OPTICS
INTERFACE
105B
RF block
RF
MUX/
DEMUR
104
MODEM
1031
1032
103 N-1
103N
SWITCH
MATRIX
102
1011
1012
1013
101N

Fig. 1

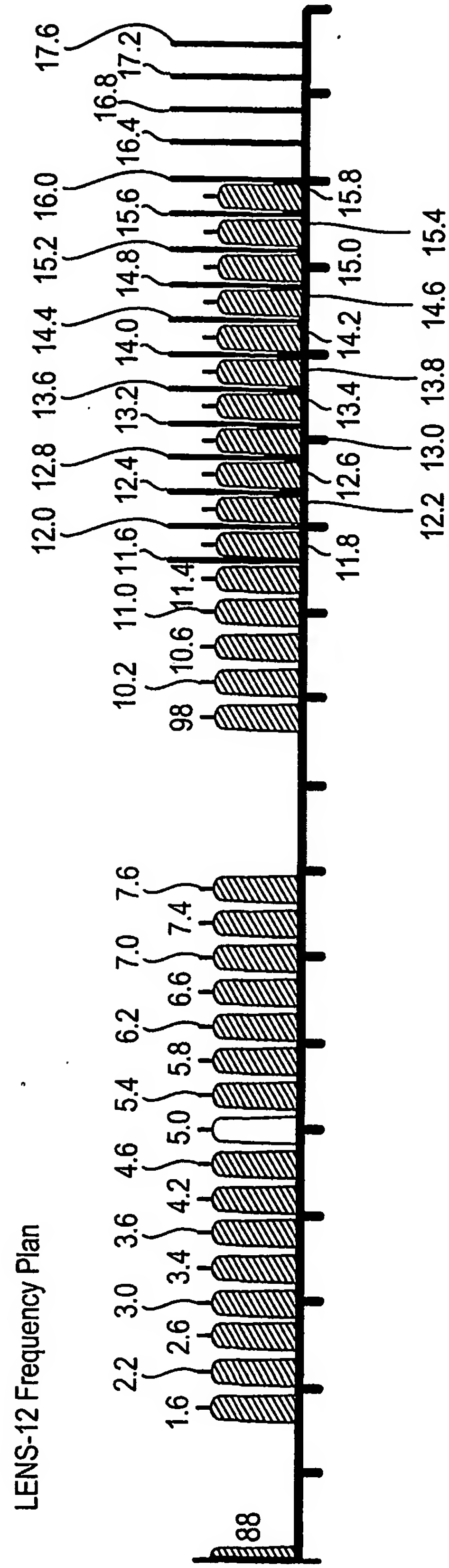
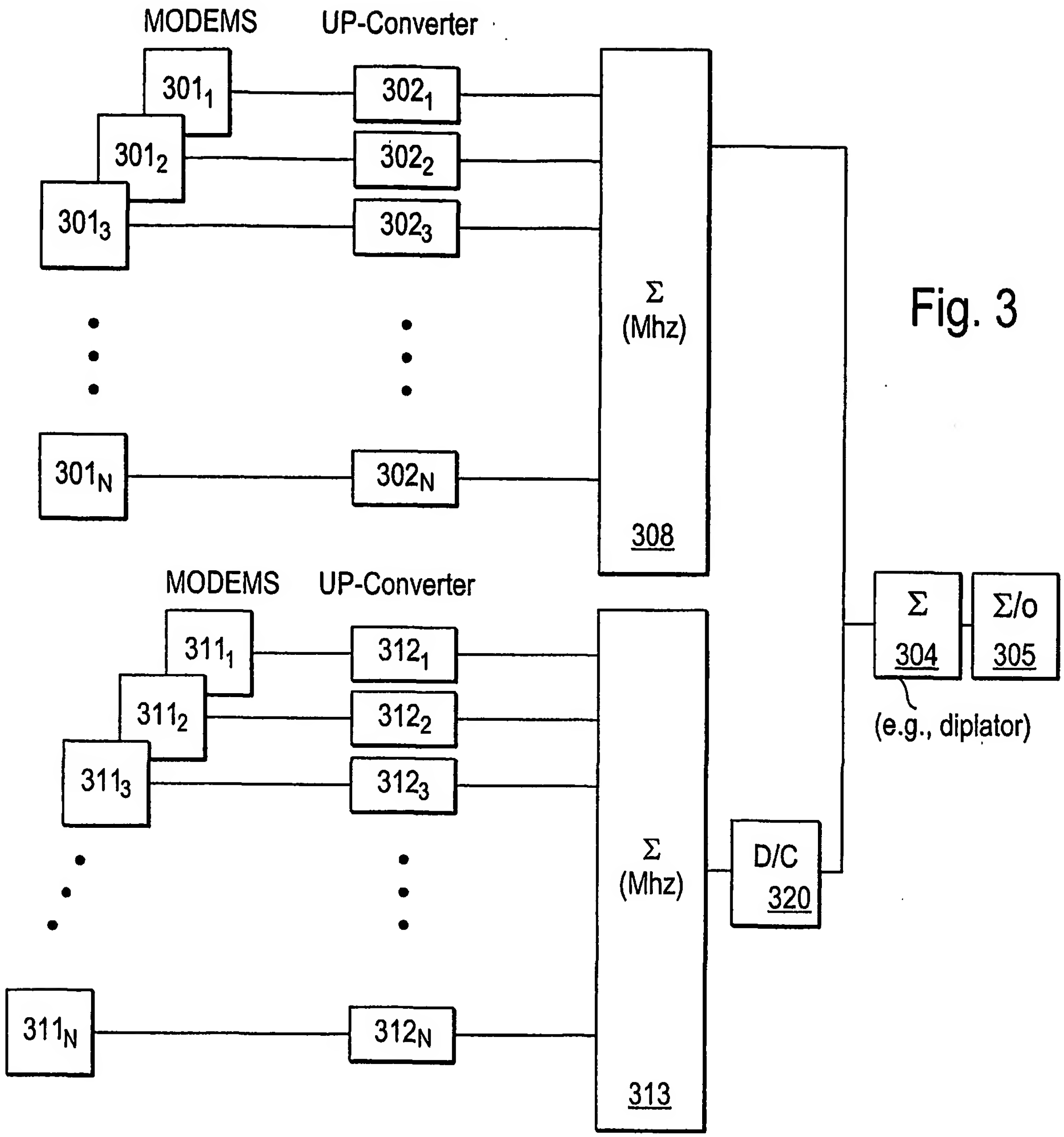
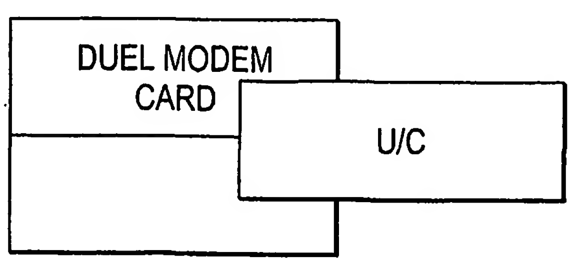

LENS-12 Frequency Plan
88
1.6
2.2
2.6
3.0
3.4
3.6
4.2
4.6
5.0
5.4
5.8
6.2
6.6
7.0
7.4
7.6
98
10.2
10.6
11.0
11.4
11.6
11.8
12.0
12.2
12.4
12.6
12.8
13.0
13.2
13.4
13.6
13.8
14.0
14.2
14.4
14.6
14.8
15.0
15.2
15.4
15.6
15.8
16.0
16.4
16.8
17.2
17.6

Fig. 2



MODEMS
UP-Converter
301_1
301_2
301_3
301_N
302_1
302_2
302_3
302_N
Σ
(Mhz)
308
MODEMS
UP-Converter
311_1
311_2
311_3
311_N
312_1
312_2
312_3
312_N
Σ
(Mhz)
313
D/C
320
Σ
304
Σ/o
305
(e.g., diplator)

Fig. 3



DUEL MODEM
CARD
U/C

Fig. 4

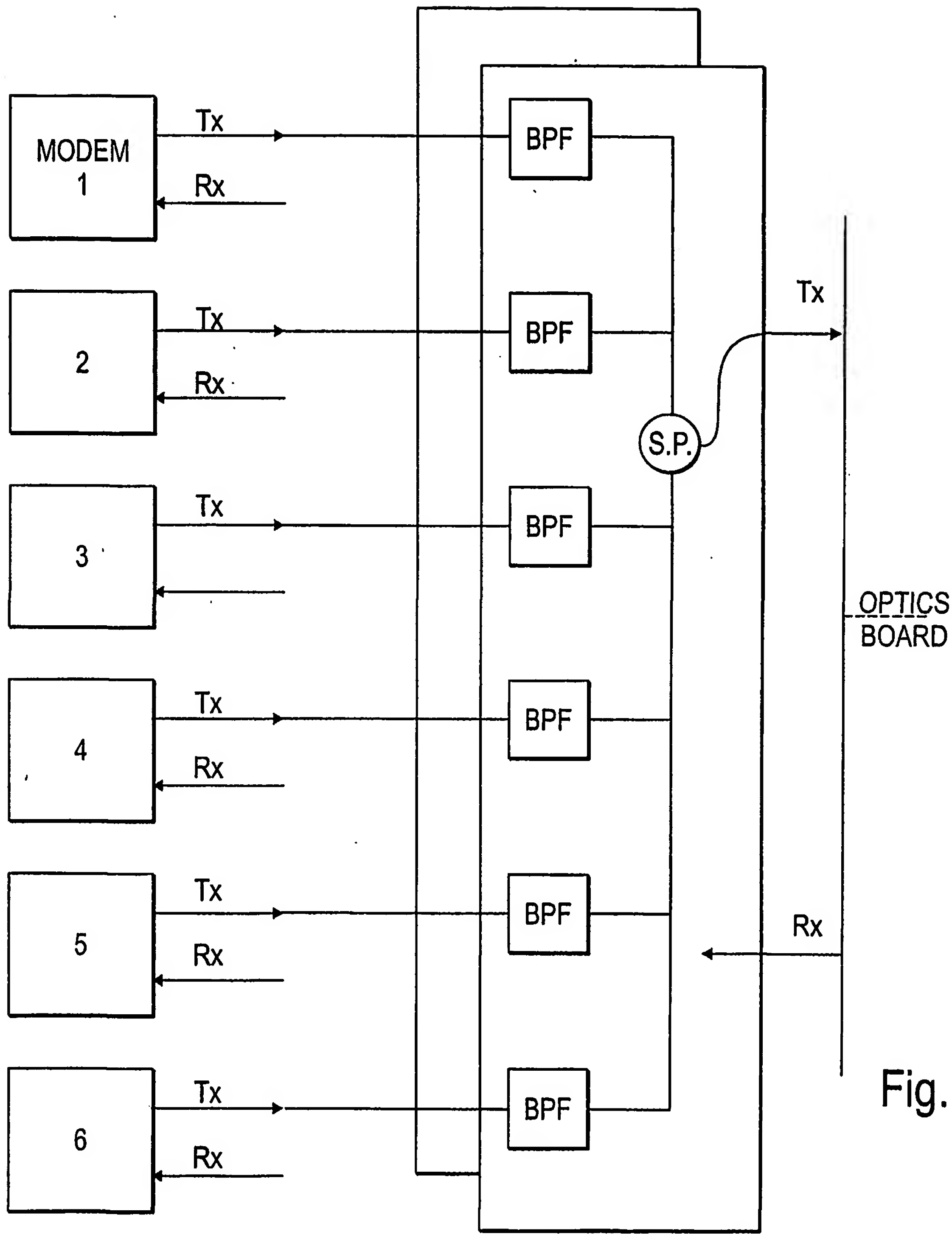
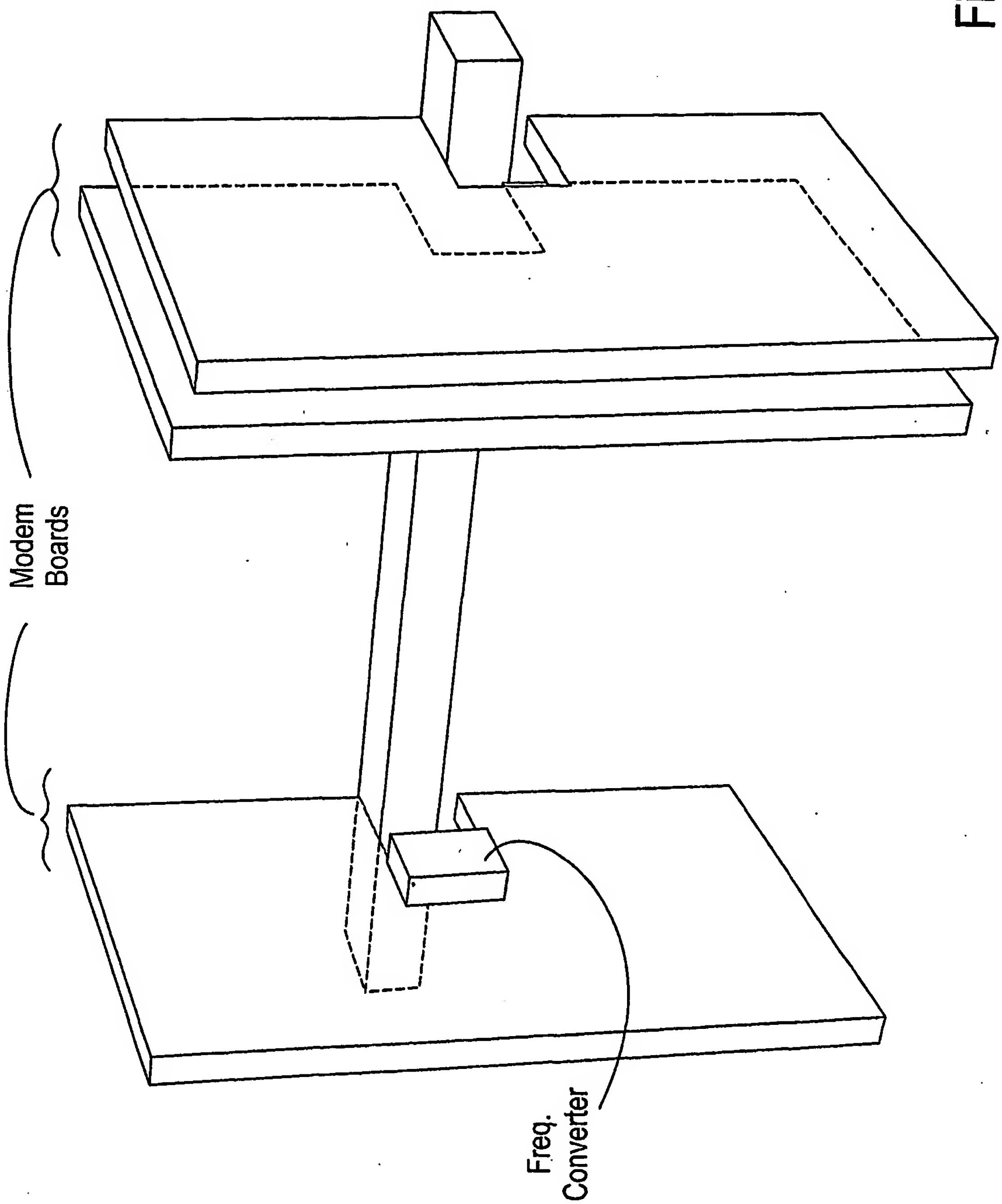

MODEM
1
Tx
Rx
2
Tx
Rx
3
Tx
4
Tx
Rx
5
Tx
Rx
6
Tx
Rx
BPF
BPF
BPF
BPF
BPF
BPF
S.P.
Tx
Rx
OPTICS
BOARD

Fig. 5

Fig. 6



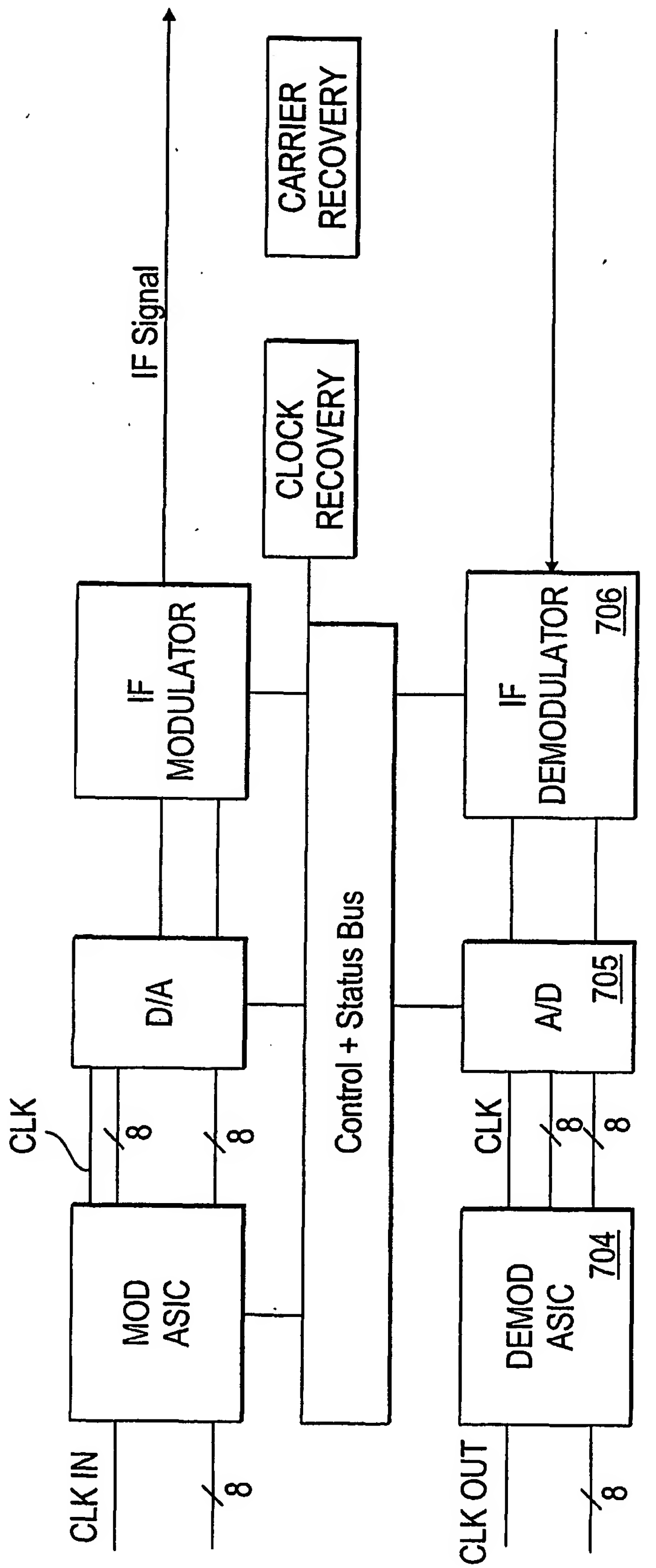

IF Signal
CARRIER RECOVERY
CLOCK RECOVERY
IF MODULATOR
IF DEMODULATOR
706
D/A
A/D
705
Control + Status Bus
CLK
8
8
CLK
8
8
MOD ASIC
DEMOD ASIC
704
CLK IN
8
CLK OUT
8

Fig. 7

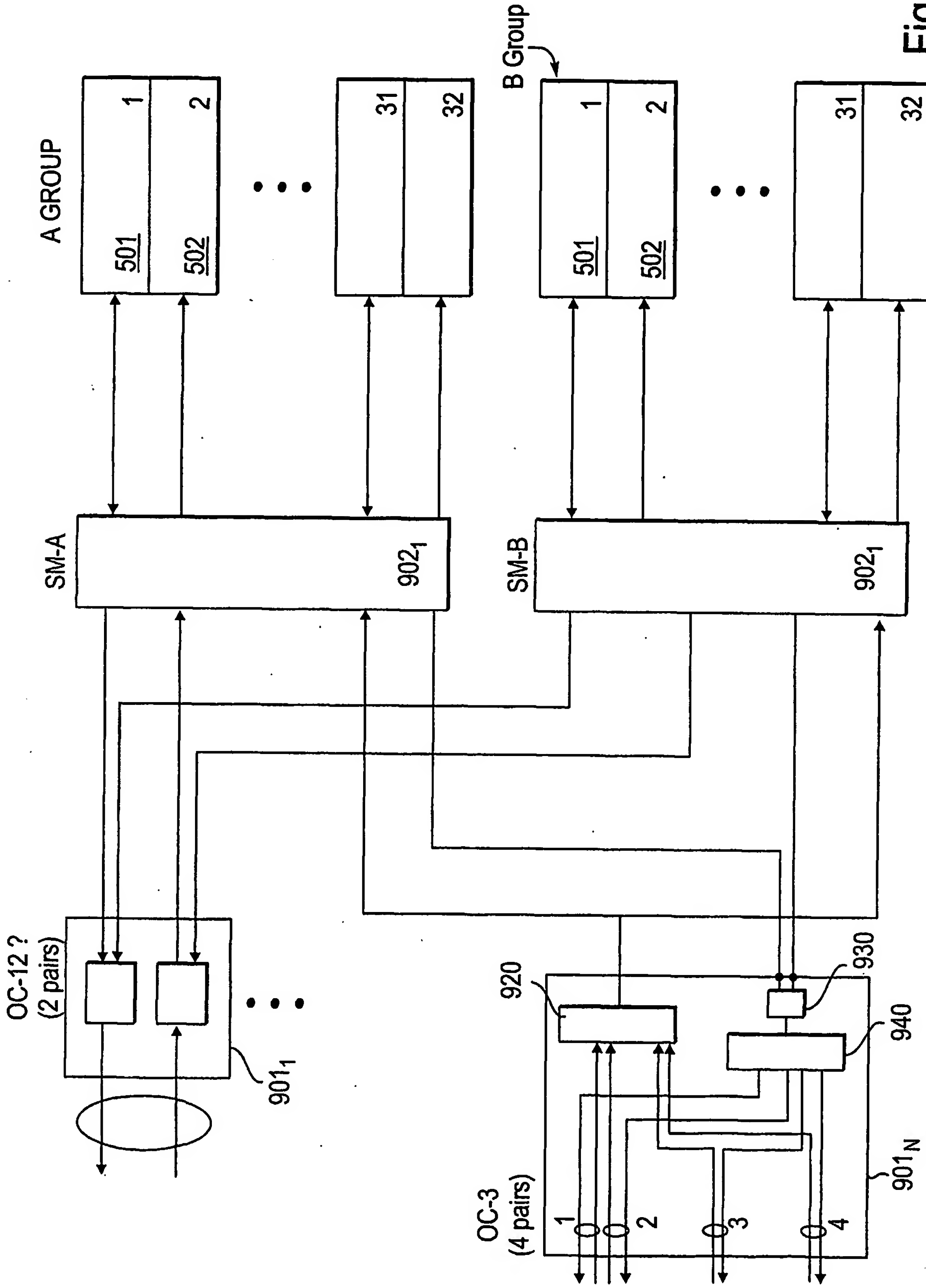

A GROUP
501
502
1
2
31
32
B Group
501
502
1
2
31
32
SM-A
902_1
SM-B
902_1
OC-12 ?
(2 pairs)
901_1
OC-3
(4 pairs)
1
2
3
4
920
930
940
901_N

Fig. 8

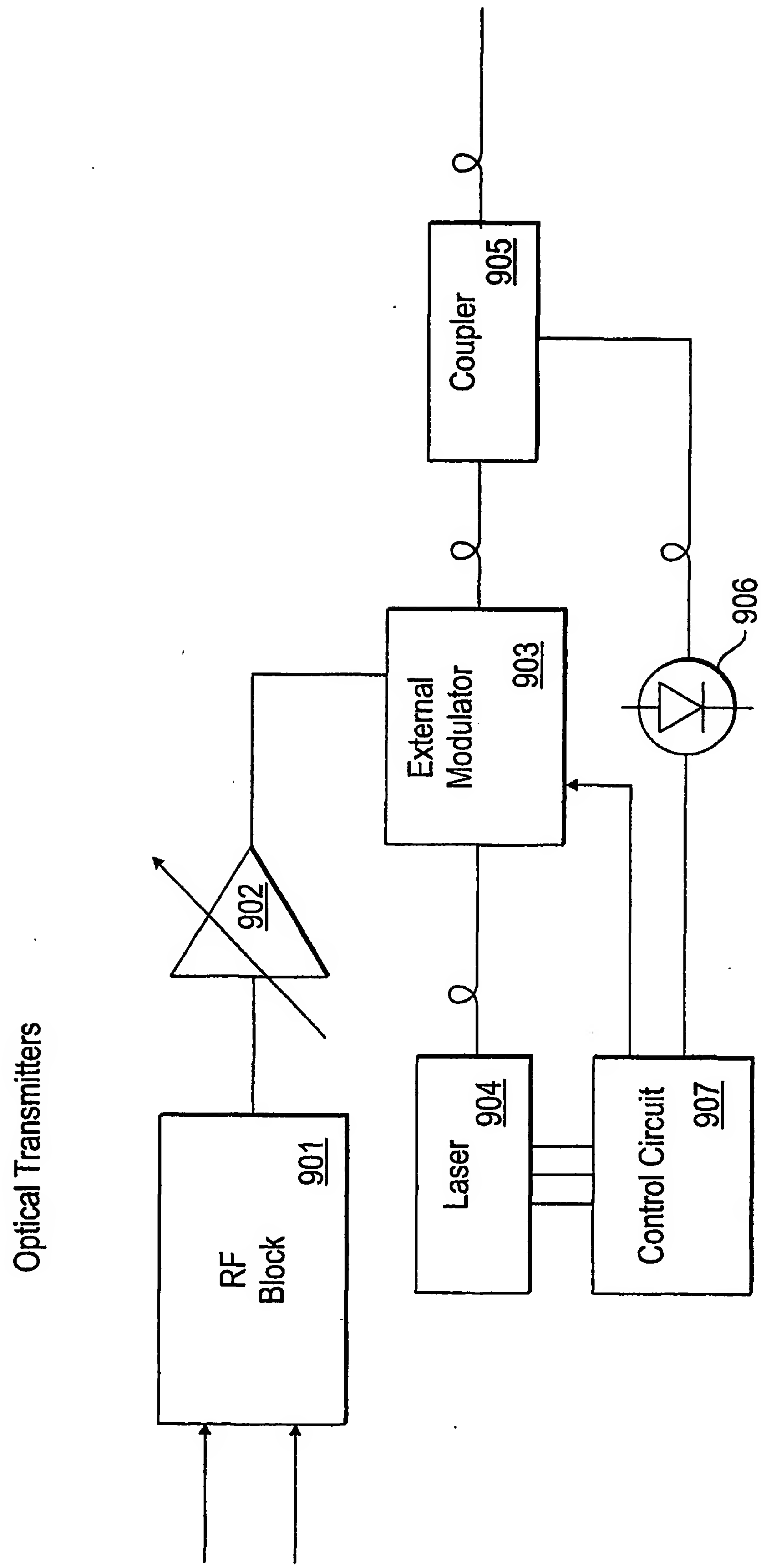

Optical Transmitters
RF Block
901
902
External Modulator
903
Laser
904
Coupler
905
906
Control Circuit
907

Fig. 9

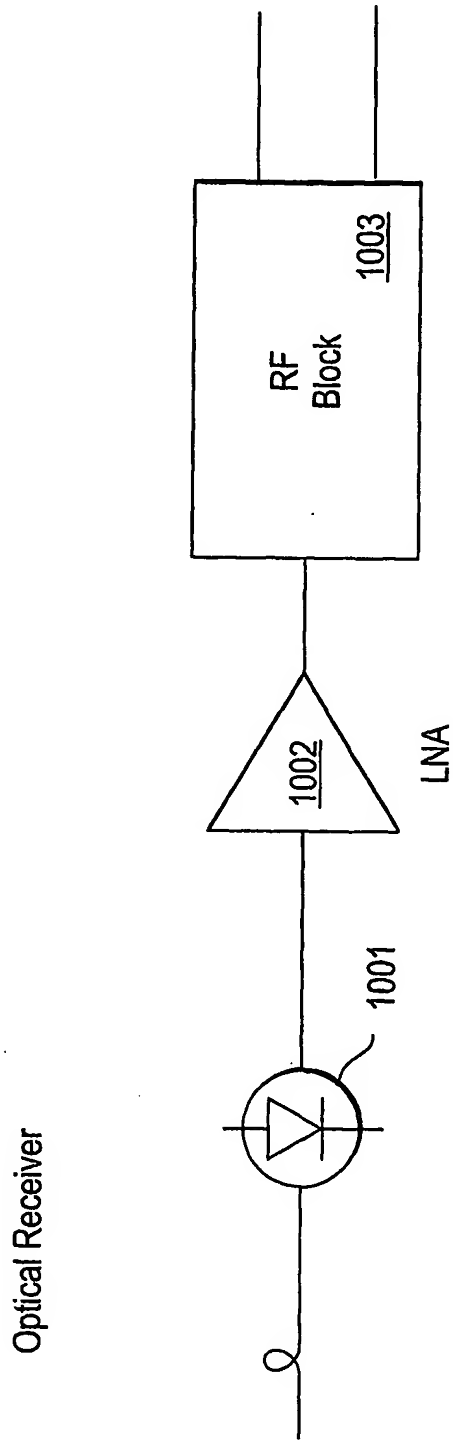


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/26587

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04J 14/02
US CL : 359/124
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/124, 125, 133, 154, 181,

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,680,238 A (MASUDA) 21 October 1997 (21.10.1997), entire document, especially Figures 1, 4A, and 9A.	1-16
Y	US 5,517,232 A (HEIDEMANN et al.) 14 May 1996 (14.05.1996), entire document, especially Figures 1-2.	1-16
Y	US 5,500,758 A (THOMPSON et al.) 19 March 1996 (19.03.1996), entire document, especially Figure 1.	1-16
Y	US 5,339,184 A (TANG) 16 August 1994 (16.08.1994), entire document, especially Figures 1, 3A-B, and 4A-B.	1-16
Y	US 5,134,509 A (OLSHANSKY et al.) 28 July 1992 (28.07.1992), entire document, especially Figures 1, 5, and 6.	1-16
Y	US 5,016,242 A (TANG) 14 May 1991 (14.05.1991), entire document, especially Figures 2 and 3.	1-16
Y	US 4,949,170 A (YANAGIDAIRA et al.) 14 August 1990 (14.08.1990), entire document, especially Figures 1 and 3.	1-16
Y	US 4,893,300 A (CARLIN et al.) 09 January 1990 (09.01.1990), entire document, especially Figure 1.	1-16
Y	US 4,722,081 A (FUJITO et al.) 26 January 1988 (26.01.1988), entire document, especially Figure 1.	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 November 2001 (02.11.2001)	03 DEC 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Jason Chan Telephone No. 703-305-4700